Transportation Infrastructure Resiliency

A Review of Transportation Infrastructure Resiliency in Light of Future Impacts of Climate Change

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Global Climate Change: The Science, Social Impact and Diplomacy of a World Environmental Crisis

Graduate Research Paper

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Abstract

The threat of global climate change and its impact on our world's infrastructure is a rapidly growing reality. Particularly, as seen in recent storm events such as Hurricane Katrina and Sandy in the United States, transportation infrastructure is on the front lines of seeing damaging impacts that are costly to repair. Although the world is becoming increasingly aware that climate change is quickly changing the physical landscape, little has been done in preparation for the coming changes. Cities, states, and in some instances countries have put together in depth climate resiliency plans outlining steps that would help in preparation for the coming changes; these plans are not common enough, and are divided and unfunded. There needs to be more action towards the protection of our transportation infrastructure, an entity that impacts the lives of people on a daily basis.

1.1. Introduction

In June of 2013, President Barack Obama released his Climate Action Plan (CAP) (Obama 2013); the president's current recognition that climate change is palpable, and something must be done to counter its effects for future generations. The CAP recognizes the effects of climate change are real, and economically, the impacts for the United States could be very costly. The National Oceanic and Atmospheric Association (NOAA) reported in 2012 alone, "…there were 11 different weather and climate disaster events with estimated losses exceeding $1 billion each across the United States. Taken together, these 11 events resulted in over $110 billion in estimated damages, which would make it the second-costliest year on record." (Smith 2013)

This paper focuses on one of the three main pillars the CAP was written around: "Preparing the United States for the Impacts of Climate Change". Within the second pillar of preparing America for the impacts of climate change, President Obama highlights different areas in which he feels are strongly vulnerable to climate changes, and need both federal and local level attention. Specifically, the President highlights the vulnerability of transportation and its associated infrastructures, saying federal agencies and local representatives need to work together to build a task force for climate preparedness, identify susceptible areas such as transportation infrastructure, and boost the resiliency of this infrastructure to prepare for future climate changes (Obama 2013). Part of this paper will be a synthesis of projects currently being done worldwide in relation to transportation climate change resiliency. A large portion of this synthesis, being both current and relevant, will focus on Mayor Michael Bloomberg's recently published PLaNYC, a report which goes into great detail about New York City's proposed initiatives as a result of the damage done during Hurricane Sandy. In his plan, the President cites Hurricane

Sandy as just one example of the devastation a single storm can have on vulnerable infrastructure and how much it can impact the local economy. The plan cites that in response to Hurricane Sandy, "… the Department of Transportation's Federal Transit Administration (FTA) is dedicating $5.7 billion to four of the area's most impacted transit agencies, of which $1.3 billion will be allocated to locally prioritized projects to make transit systems more resilient to future disasters. FTA will also develop a competitive process for additional funding to identify and support larger, stand-alone resilience projects in the impacted region" (Obama 2013).

This research paper is in response to the President's CAP and a first step in assessing the vulnerable transportation infrastructures associated with the United States (US). First, a review of current transportation related infrastructure in the US will be summarized. Then, a synthesis of climate resiliency publishing's will be presented to show the current weaknesses in the country's transportation infrastructure and highlight recommendations for the future. The closing portion of this essay will be a personal interpretation of this problem from the eyes of a transportation environmental specialist.

1.2. Infrastructure Review

The US has about 4 million miles of roads, 30,000 wastewater treatment and collection facilities, and over 800,000 federal facilities (NRC 2010). This national infrastructure connects communities, protects public health and the environment, and facilitates trade and economic growth, among other important functions. This infrastructure is mostly owned and operated by state and local governments (NRC 2010). According to a 2010 Congressional Budget Office report, total public spending on transportation and water infrastructure exceeds $350 billion

annually, with roughly 25 percent of this amount coming from the federal government and the rest coming from state and local governments (CBO 2010). Specific to the federal government alone, according to the General Services Administration (GSA), the federal government's portfolio of building assets totaled approximately 3.35 billion square feet of space with a total operating cost of $30.8 billion (GSA 2010).

The American Society of Civil Engineers (ASCE) states the average bridge in the United States is designed to last 50 years, and EPA data indicates facilities such as wastewater treatment plants typically have an expected useful life of 20 to 50 years before they require expansion or rehabilitation (NRC 2010). Much of the United States' infrastructure is currently in poor condition; the ASCE gives the US infrastructure a D+ rating in its "Infrastructure Report Card". In this report, the ASCE states many wastewater treatment plants were built over 50 years ago and do not have the capacity to treat increasing volumes of water, road and bridges receive a low grade due to identified structural deficiencies, public transit systems are deficient and deteriorating, costing the economy $90 billion in regular maintenance in 2010 and the inland waterways system has not been updated since the 1950s with more than half of the water locks over 50 years old (ASCE 2013). The ASCE estimates the US would have to dedicate $3.6 trillion by 2020 to bring the current infrastructure to acceptable, safe standards (ASCE 2013); that is with current climate conditions, not accounting for the expected climate changes.

With impending climate changes for the US, impacts to critical transportation infrastructure are becoming more of a threat then a possibility. For the gulf coast area alone, 27 percent of the major roads, 9 percent of the rail lines, and 72 percent of the ports are built on land at or below

122 cm (4 feet) in elevation. More than half of the area's major highways (64 percent of Interstates; 57 percent of arterials), almost half of the rail miles, 29 airports, and a majority of the ports are below 7 m (23 feet) in elevation and subject to flooding and possible damage due to hurricane storm surge (CCSP 2008). The rising sea level, only one variable in the future of climate change, was modeled by the International Panel on Climate Change to rise anywhere from .18-.59 meters (7-23 inches), excluding rapid dynamical changes in ice flow (IPCC 2012). Other model projections incorporated in the IPCC report show seas rising up to 1.9 m (75 inches) by the end of the century (IPCC 2012). This model of mean sea level rise is the world average, but relative (local) sea level rise[1] could be even more severe. For example, assuming historical geological forces continue, a 2-foot rise in global sea level by the end of the 21st century would result in a relative sea level rise of 2.3 feet at New York City (Figure 1), 2.9 feet at Hampton Roads, Virginia, 3.5 feet at Galveston, Texas, and 1 foot at Neah Bay in Washington state (USGCRP 2009).

[1] Relative sea level is defined as "Position of sea level relative to the land. RSL change measures the land movement versus the water movement over time." http://museum.gov.ns.ca/mnh/nature/nhns2/glosntoz.htm#r. This means that changes in sea level are due not only to current changes in ocean levels, but also movements of the continental crust.

Figure 1 - Gulf Coast Area Transportation Infrastructure at Risk Due to Sea Level Rise

Source: USGCRP 2009

The United States Global Change Research Program (USGCRP) summarizes future threats to transportation due to climate change (USGCRP 2009):

- Sea-level rise and storm surge could increase the risk of major coastal impacts, including both temporary and permanent flooding of airports, roads, rail lines, and tunnels.
- Flooding from increasingly intense downpours could increase the risk of disruptions and delays in air, rail, and road transportation, and damage from mudslides in some areas.
- The increase in extreme heat could limit some transportation operations and cause pavement and track damage. Decreased extreme cold will provide some benefits such as reduced snow and ice removal costs.
- Increased intensity of strong hurricanes would lead to more evacuations, infrastructure damage and failure, transportation interruptions, and fatalities.
- Arctic warming would continue to reduce sea ice, lengthening the ocean transport season, but also resulting in greater coastal erosion due to waves.

1.3. Current Infrastructure Resiliency Initiatives

Although impacts to the critical transportation infrastructure of the US are in growing concern, there are alternatives that can be taken to help alleviate damages. Since much of the critical infrastructure is reaching the end of its projected constructed lifespan (ASCE 2013), now is the time for resilient initiatives that will prepare the infrastructure for future generations. In light of

recent extreme storm events like Hurricane Katrina which impacted New Orleans, and more recently Sandy which devastated coastal New York, plans and recommendations are already being put into place to revolutionize the transportation sector worldwide, and make tomorrow's transit possible. This section will be a synthesis of these initiatives, focusing heavily on the newest report published for New York City.

Mayor Michael Bloomberg of New York City put forth his *PLaNYC* strategy for a stronger, more resilient New York after the impacts of Sandy devastated the coastal city. New York City Transportation, with over 7.6 million subway and bus riders, 2 million drivers, and 850,000 commuter rail riders daily (Moss 2012), was one of the areas most impacted. Highlights from this plan include:

Protecting assets to maintain system operations (Bloomberg 2013):

Since climate change predicts that future extreme storm events are going to occur, some planned infrastructure changes include:

- Reconstruct and upgrade streets damaged by Sandy to include resiliency features;
- Integrate a variety of climate resiliency features into future street reconstruction projects including water management best practices and tools. These features allow water captured on streets to soak into the ground rather than flow into the sewer system, resulting in lower drainage loads on both sewers and wastewater treatment plants;
- Installing bioswales (planted areas in the sidewalk designed to capture stormwater from the adjacent roadway) and/or pre-cast permeable concrete gutters, and adding or raising bulkheads top help prevent street flooding;
- Make sure traffic signal electronics are above flood levels and include emergency generators;
- Install floodgates and raise entrances to flood vulnerable traffic tunnels;
- Integrate climate change resiliency into planning and project development where it was not previously considered.

Preparing the transportation system to restore service after extreme climate events (Bloomberg 2013):

A main issue surrounding hurricane Sandy was the time it took for transportation modes and access to become fully operational, and some still are not. Proposed upgrades to help resume normal transportation when systems have been overwhelmed by large storm events include:

- Have a back-up emergency transit system in place when major modes are inundated;
- Work with a wide range of transportation agencies and other stakeholders around the region to identify the critical elements of the surface transportation network that need to be available quickly following different types of events;
- Implement high occupancy vehicle protocols for emergency situations to avoid vehicular traffic congestion;
- Plan for and install new pedestrian and bicycle facilities to improve connectivity to key transportation hubs;
- Update and construct new ferry landings, as well as purchase new ferries that can tolerate more extreme weather conditions;
- Improve communication from government agencies to the general public about transportation shut downs and restorations.

Implementing new and expanded services to increase system flexibility and redundancy (Bloomberg 2013):

This plan realizes that actions need to be taken not only to solve problems when they occur, but to prevent them as well. A couple initiatives were proposed that will expand current transit services in a climate resilient way, such as:

- Expand the cities bus networks and bus priority corridors to accommodate commuters when subway lines are unavailable;
- Expand key ferry services and infrastructure that transport commuters from surrounding islands into the city;

Another part of the report outlines alternatives for general coastal shoreline protection. With over 520 miles of shoreline, Bloomberg realizes that although there are several variables to climate change, shoreline impacts are likely to be the most severe and costly. The study cites that

the greatest risk to New York City in the near future is a storm surge, which is exactly what happened during Sandy. High tides, heavy winds and precipitation, and a high storm surge all came together to create one extreme weather event. These strategies include:

Increasing coastal edge elevations (Bloomberg 2013) (See Appendix 1 for Planned Action Images):

The beach acts as a first line of defense for storm surges and wave action for the surrounding land. During Hurricane Sandy, much of this defense line was washed away or destroyed. New York has posed severe action to help rebuild this defense, and make it stronger.

- Continue to work with the US Army Corp of Engineers (USACE) to complete emergency beach nourishment in heavily impacted areas such as Coney Island, Rockaway Peninsula, and Staten Island, including repairing beach facilities for public use by summer 2013;
- Install shoreline revetments in impacted beach areas to help decrease wave energy during storm surges;
- Eight percent of the city shoreline will be at risk of regular flooding by 2050; to prepare for this the city plans to raise bulkheads and other shoreline structures to minimize the risk of regular flooding in targeted neighborhoods;
- Rebuild bulkheads, flood gates, and tide gates in areas exposed to be vulnerable due to Sandy. These will help to make surrounding neighborhoods more resilient to future flooding.

Minimizing Upland wave zones (Bloomberg 2013):

- Work with the USACE to conduct and implement various coastal protection projects for vulnerable areas, such as:
    - Installing primary and secondary dune systems along Rockaway peninsula for increased wave energy protection;
    - Investigate the pilot study of installing an offshore breakwater system adjacent and south of Great Kills Harbor; this study will be used as a pilot to assess the effectiveness of such a system;
    - Wetland restoration projects at various lowland beach sites to help improve natural flooding patterns;
    - Conduct a “Living Shoreline” project consisting of oyster reef breakwaters, beach nourishment, and maritime forest enhancements for the neighborhoods around Tottenville;

- Complete previous breakwater and sea gate projects around the coast for wave attenuation with current climate change variables in mind.

Protecting against storm surges (Bloomberg 2013):

The area of New York City is unique in the fact that the entire coast is not what one would think of as "normal" eastern coastline. The existing engineered conditions of New York coasts and current land use will inhibit the deployment of traditional measures such as levees or permanent floodwalls in some areas. To reduce this risk; with flood risks systems in mind that worked worldwide in locations such as the Netherlands, the United Kingdom, and Midwestern USA; New York proposes a global design competition for the creation of unique ways to reduce flood risk. This "integrated flood protection system" would be implemented in areas such as Hunts Point, East Harlem, the lower east side of Manhattan, Hospital Row, Red Hook, Staten Island, and Newton Creek.

Improving coastal design and governances (Bloomberg 2013):

- Expedite a coastal flooding protection report by the USACE that will highlight vulnerable flooding areas and propose management alternatives;
- Continue to make waterfront recreation a priority for the public, by:
  - Implementing a centralized waterfront inspection program for its entire portfolio of coastal and waterfront assets;
  - Partner with non-governmental entities to investigate innovative alternatives to coastal protection and infrastructure resiliency;
  - Identify and minimize the risk of drainage pipe flooding;
  - Continue to investigate possibilities for wetland rehabilitation;
  - Work with government agencies to continue to identify flooding hazards and propose protection alternatives

Funding for these initiatives were estimated to amount over $14 billion dollars of public funding over a ten year period; other smaller resiliency projects, more specific to Sandy rehabilitation, amount to about another $5.5 billion (Bloomberg 2013). These values are determined only for

the initial stages of the initiatives descried above, complete full design and implementation funds would have to be determined at a project by project basis.

The Federal Highway Administration (FHWA) conducted a pilot program project, which funded state DOTs and MPOs to implement a conceptual model which is used to conduct vulnerability and risk assessments of transportation infrastructure; the results of this study were used to help refine the model into the Climate Change & Extreme Weather Vulnerability Assessment Framework (FHWA 2012). This study helped to outline how to assess the vulnerability from climate change impacts, and how to implement these vulnerabilities into future decision making. Stemming from this pilot study, FHWA is now partnering with several state DOTs, NPOs and federal land management units to conduct climate change and extreme weather vulnerability assessments of transportation infrastructure and to analyze options for adapting and improving resiliency (FHWA 2012). Several states, through this studies implementation, are now conducting climate change vulnerability assessments of their owned transportation infrastructure, and looking for ways to implement resiliency replacements or upgrades for future climate changes.[2]

After the devastation to the Gulf Coast after Hurricane Katrina in 2005, large scale initiatives have been put in place to upgrade the areas, especially New Orleans, transportation and infrastructure resiliency. The Louisiana State University Gulf Coast Center for Evacuation and Transportation Resiliency is one of these major initiatives that publish papers on the current

[2] For a full listing of participating states in the FHWA pilot study please visit https://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/vulnerability_assessment_pilots/2013-2014_pilots/index.cfm

resiliency projects throughout the state.[3] Several evacuation and emergency plans and systems have been improved and made more resilient for future extreme storm evens. Improvements include planned evacuation routes, evacuation lodging, improved evacuation communication, and planned evacuation transportation (Fogarty 2011). Resilient light rail transit systems to replace those destroyed by Katrina have been proposed and funded to help facilitate local transportation needs. These include a potential intercity rail connection project between New Orleans and Baton Rouge and a streetcar project in downtown New Orleans (Amdal 2011). The construction of the new Twin Span Bridge across Lake Pontchartrain has been designed to supposedly provide a 100 year lifespan for the infrastructure. This bridge, one of the major transportation infrastructure projects implemented after the damage of Katrina, extensively uses high performance concrete which is thought to increase the lifespan of the bridge, and resist storm surge impacts (LDOT 2011).

The creation of a climate change resilient city is not a new idea for some countries; for areas of the world that have been dealing with storms and flooding events similar to Sandy for years, steps have already been taken to protect their homes. The Asian Cities Climate Change Resilience Network (ACCCRN), whose chairmen sat on the board that helped create the Bloomberg report to a more resilient city, currently is working with over 50 Asian cities to implement new climate change interventions such as land use planning, drainage and flood management, emergency response systems, ecosystem strengthening, and disease surveillance. Another project from the ACCCRN is the "100 Resilient Cities Centennial Challenge", which was created as competition for any cities who wish to enter with winners receiving membership to their network of resilient cities members, a chief resilience officer who will oversee

[3] For a full listing of these projects visit http://evaccenter.lsu.edu/projects.html#11-02

development of resiliency strategies, and tools and resources to help support the creation of a city resiliency plan (Rockefeller Foundation 2013).

The Rockefeller Foundation tracks grants awarded to different agencies worldwide that are developing climate change resiliency projects. To date, over 17 projects with budgets over $1 million have been funded by various sources; these projects encompass various climate change initiatives and resiliency plans for different communities worldwide.[4] The World Bank is involved in several transportation resiliency projects worldwide, including Increasing Resilience to Climate Change and Natural Hazards in Vanuatu (World Bank 2013), as well as the rehabilitation of roads and important transit routes to make transportation more resilient in Mozambique (World Bank 2010). The Ministry of Transport in Columbia, whose countries transportation infrastructure ranks 126 out of 144 nations in terms of quality, is using the timing of the failing transportation system to make necessary resiliency upgrades. The department is working to create a "Climate Change Adaptation Plan" which hopes to increase future infrastructure resiliency and maximize the yield of public investment (Martinez 2013).

1.4. Conclusion

Climate Change is a real and powerful force that will likely shape this world for future generations. Vast cultural and economic systems, such as transportation infrastructure, which have in the past been tested only by inadequacy due to age and newer technology, will now need to be built adaptively with future unforeseeable events in mind. The United Nations Framework Convention on Climate Change (UNFCCC) describes climate adaptation activities into five

[4] For full listing of grants, please visit http://www.rockefellerfoundation.org/grants/search?amountTypes=8&initiativeIds=1&page=2&limit=10

components: observation; assessment of climate impacts and vulnerability; planning; implementation; and monitoring and evaluation of adaptation actions (UNFCCC 2013). Although I believe that this is sound guidance, I fear that the United States, along with other industrialized countries of the rest of the world, are becoming too caught up in the planning stages of these steps, and are being forced to act reactively to events that could be prevented with proactive actions. The Transportation Research Board, back in 2008, presented a paper highlighting the potential impacts on climate change in the United States (TRB 2008). This report gives a detailed description of the major climate effects that are thought to impact the United States transportation system, and then splits those impacts up by modes. An older report in 2007 was published focusing on adapting cities with new resilient infrastructure to prepare for future climate change events; these studies have been done, and the recommendations are out there. I feel the boundary that stops us from truly preparing for the future is political; a barrier created by policy makers who care more about votes than facts.

My recommendations for the future would be straightforward; create an agency or association whose mission is to collect and synthesize current reports and data for climate change impacts and initiatives, rank these initiatives in order of importance, and implement them. This solution would be a streamlined process to the current way of infrastructure maintenance and building. Currently, the normal process for the maintenance of construction of transportation infrastructure is to award a grant to a federal agency who would be in control of said structure, they then propose an alternative, conduct Council on Environmental Qualities and National Environmental Policy Act standards for analyzing environmental impacts, hire contractors, and build the planned infrastructure. Although this is a laborious and time consuming task, sometimes taking

several years or decades to achieve, it has worked in the past where time was not a limiting factor. Unfortunately, processes that could take years in the future could mean the difference between saving a city, or letting it drown.

I currently work as an environmental scientist for the Federal Department of Transportation, specifically on the NEPA compliance team for the Environmental Science and Engineering division. I have become quite familiar with the environmental compliance process and see how long and involved it is to get construction projects completed. Though it is necessary to have this assessment process, in the eyes of rapidly changing climate, we need to expedite decisions to allow for proper adaptation. This idea of infrastructure resiliency and adaptation is something new for our country; currently, there are usually only two ways that something gets built; through the lengthy timeframe previously described or through emergency action, such as after a storm event. Unfortunately, this sets our government to only work two ways, either slowly or reactively. My recommendation is to create an entity within the government that is given these "emergency" expedited powers, and charged with creating and implementing a hierarchal plan for protecting our infrastructure. We need to be able to realize that in order to prevent the need for emergency action after a massive hurricane; we need to act proactively and rapidly. We need a process that lets our government agencies implement actions that will make vulnerable infrastructure more resilient. 2005 saw one of the greatest extreme weather events in the United States' history in terms of deaths and infrastructure damage; a storm that was soon to be overcome only a few years later in 2012. These storms are going to continue, everyday climate is going to change, and the geology of the United States is going to shift. My hope is that the US

can exponentially increase its investment into climate resiliency, and make strides to become more of a global role model rather than a hindrance.

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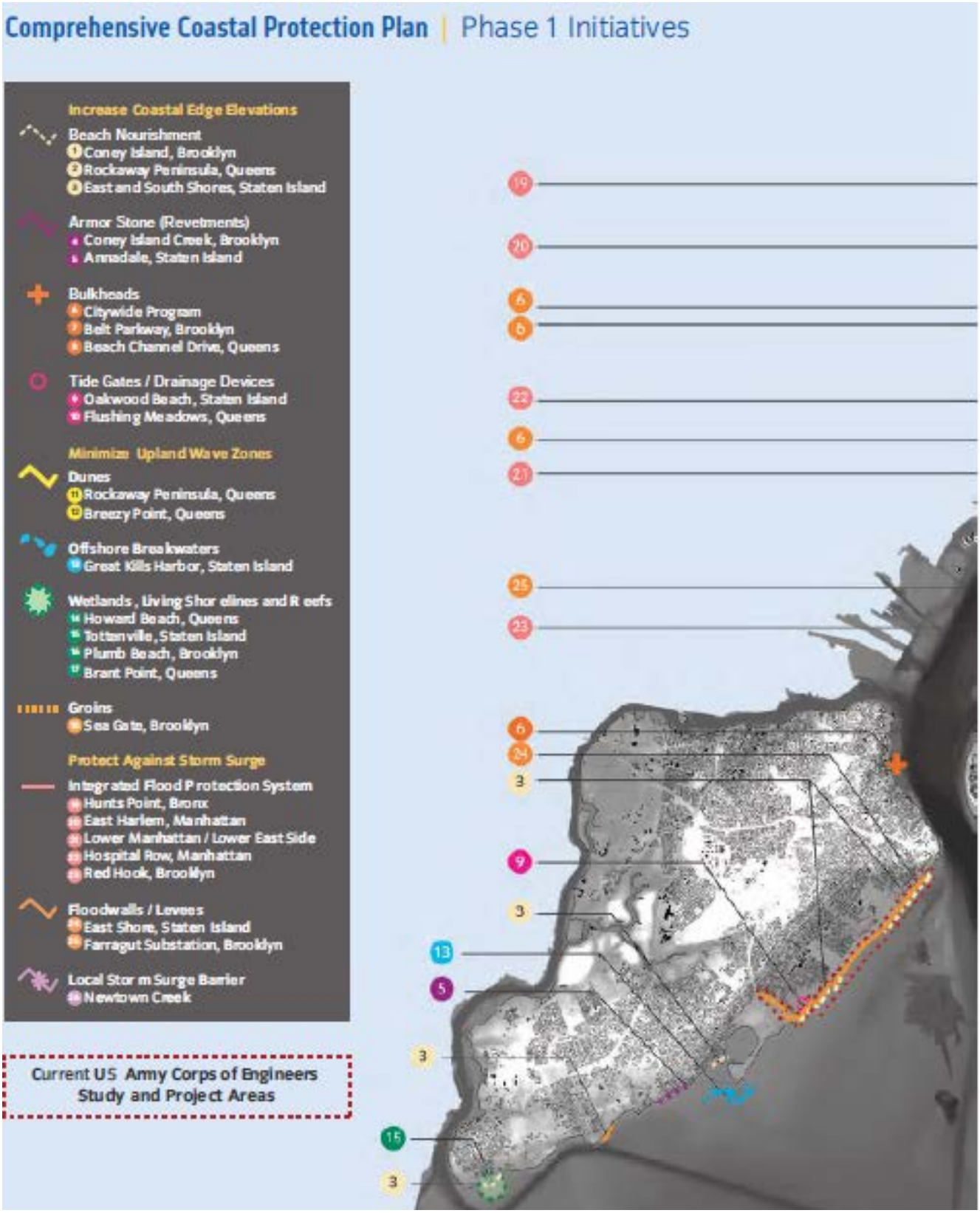
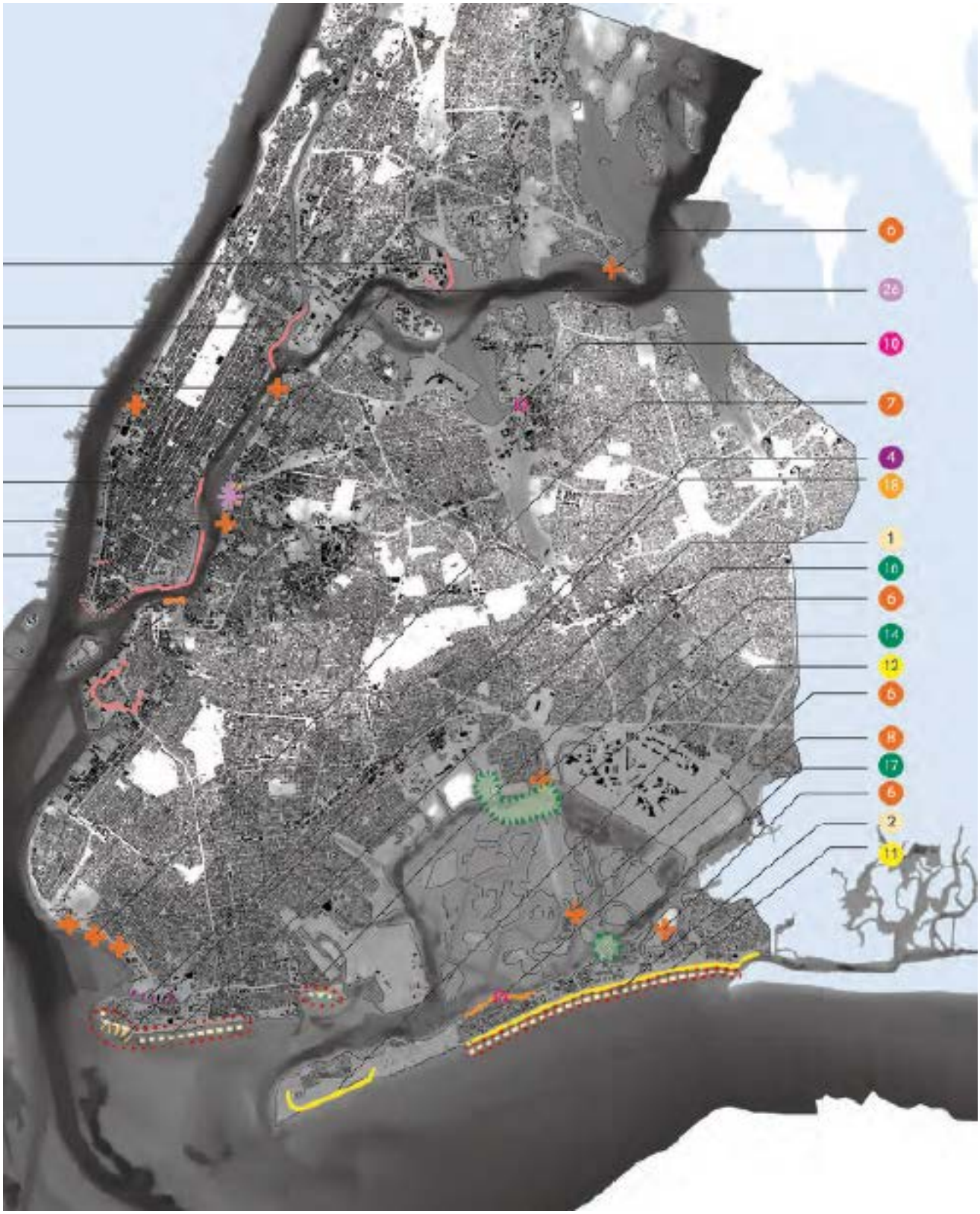
1.6. Appendix 1

PLaNYC Coastal Protection

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